# Air Force Research Laboratory


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## Forecasting Solar Indices with ADAPT

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**Space Weather Workshop**

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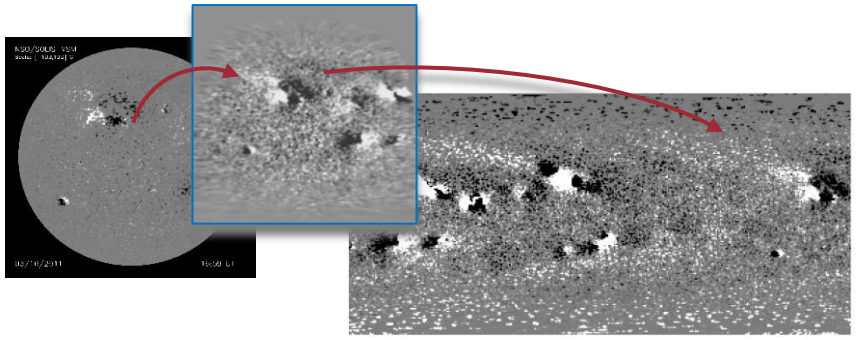
AFRL

# Air Force Data Assimilative Photospheric Flux Transport (ADAPT)

The ADAPT* model generates global solar photospheric magnetic field maps using flux transport that accounts for known surface flows in the solar photosphere:

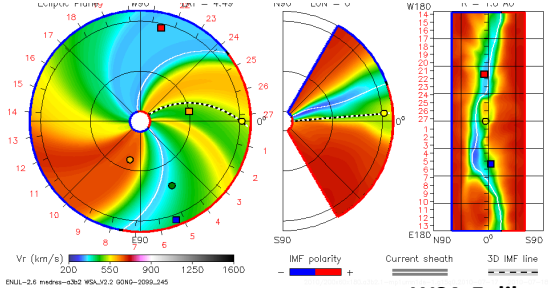
- *differential rotation*
- *meridional circulation*
- *supergranular diffusion*



*Example ADAPT Global Solar Magnetic Map*

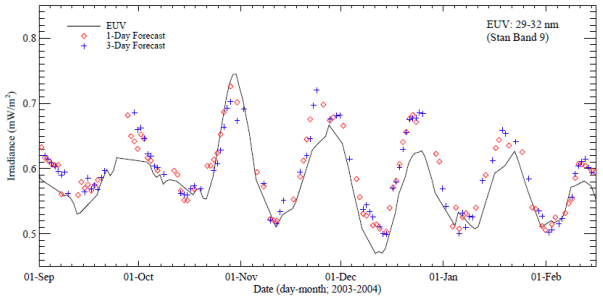
Global magnetic maps are utilized to drive:

- coronal & solar wind models used to forecast wind parameters and Coronal Mass Ejection (CME) arrival times




WSA-Enlil

- empirical models to forecast $F_{10.7}$ and XUV/EUV/FUV irradiance 1 to 7 days in advance for thermospheric modeling




*ADAPT References: Arge et al. 2013; Hickmann et al. 2015

# ADAPT Maps *Online*

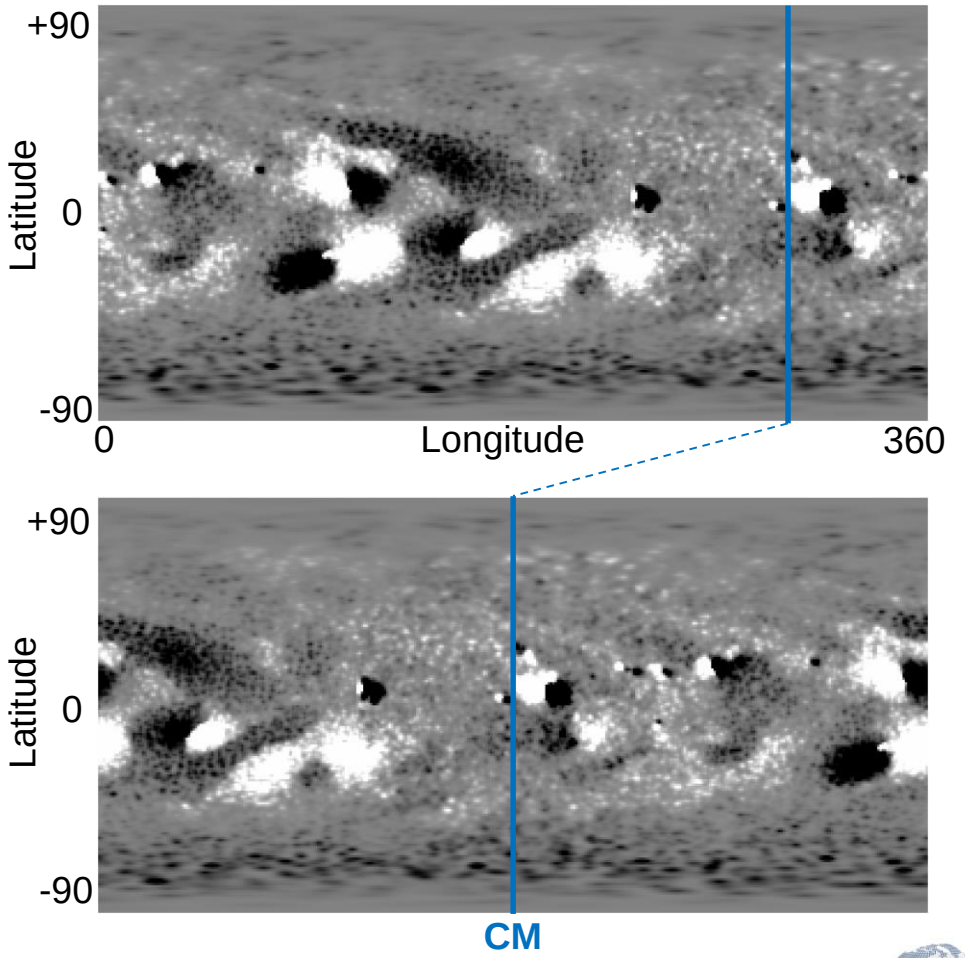
Two types of ADAPT/GONG maps are generated daily at the National Solar Observatory (NSO) at: **ftp://gong2.nso.edu/adapt/maps/**

**Carrington Frame**

Sub-directory: public/gong/.
Prefix: “adapt403”
Cadence: 12 hours
Realizations: 12*

**Central Meridian Frame**

Sub-directory: noaa/..
Prefix: “adapt413”
Cadence: 2 hours
Realizations: 12*




Example ADAPT maps for 05nov2015 @ 12 UT

* *Currently, realizations only differ by supergranulation flow pattern.*

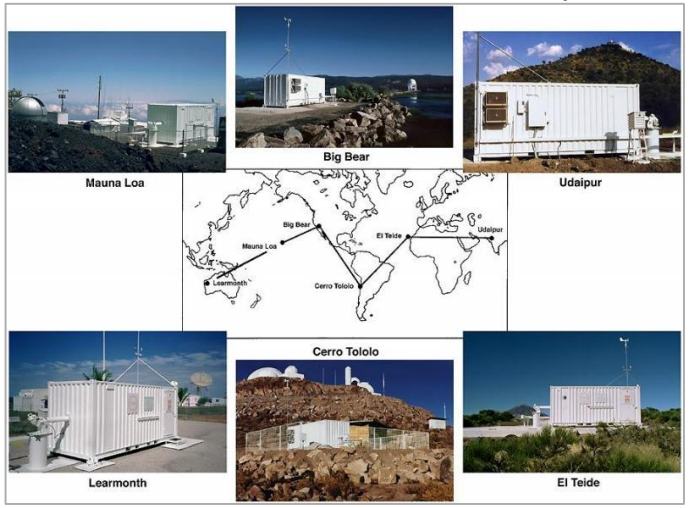
# ADAPT Solar Magnetogram Sources

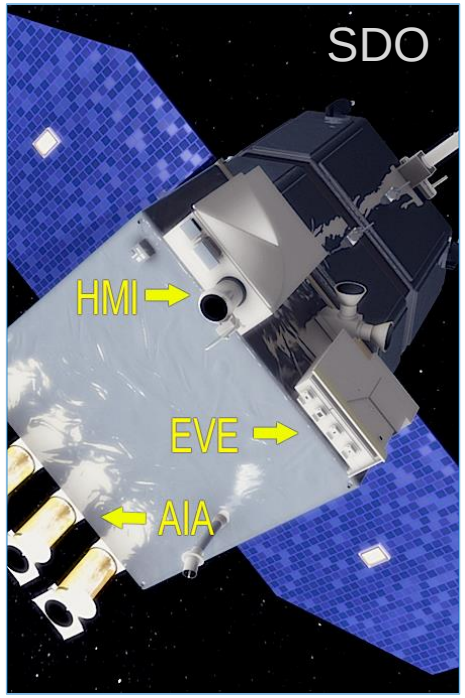
**K**itt **P**eak **V**acuum **T**elescope

**N**SO **I**ntegrated **S**ynoptic **P**rogram **V**ector **S**pectro**M**agnetograph

**KPVT: 1977 – 2003**
[24 hr, single site, 868.8 nm]
**NISP/VSM: 2003 – present**
[24 hr, single site, 630.2 nm]
**NISP/GONG: 2006 – present**
[10 min, 6 sites, 676.8 nm]
**SDO/HMI: 2010 – present**
[12 min, Sat-GEO, 617.3 nm]

**N**SO **I**ntegrated **S**ynoptic **P**rogram
**G**lobal **O**scillation **N**etwork **G**roup




**H**elioseismic and **M**agnetic **I**mager (on the **S**olar **D**ynamics **O**bservatory)

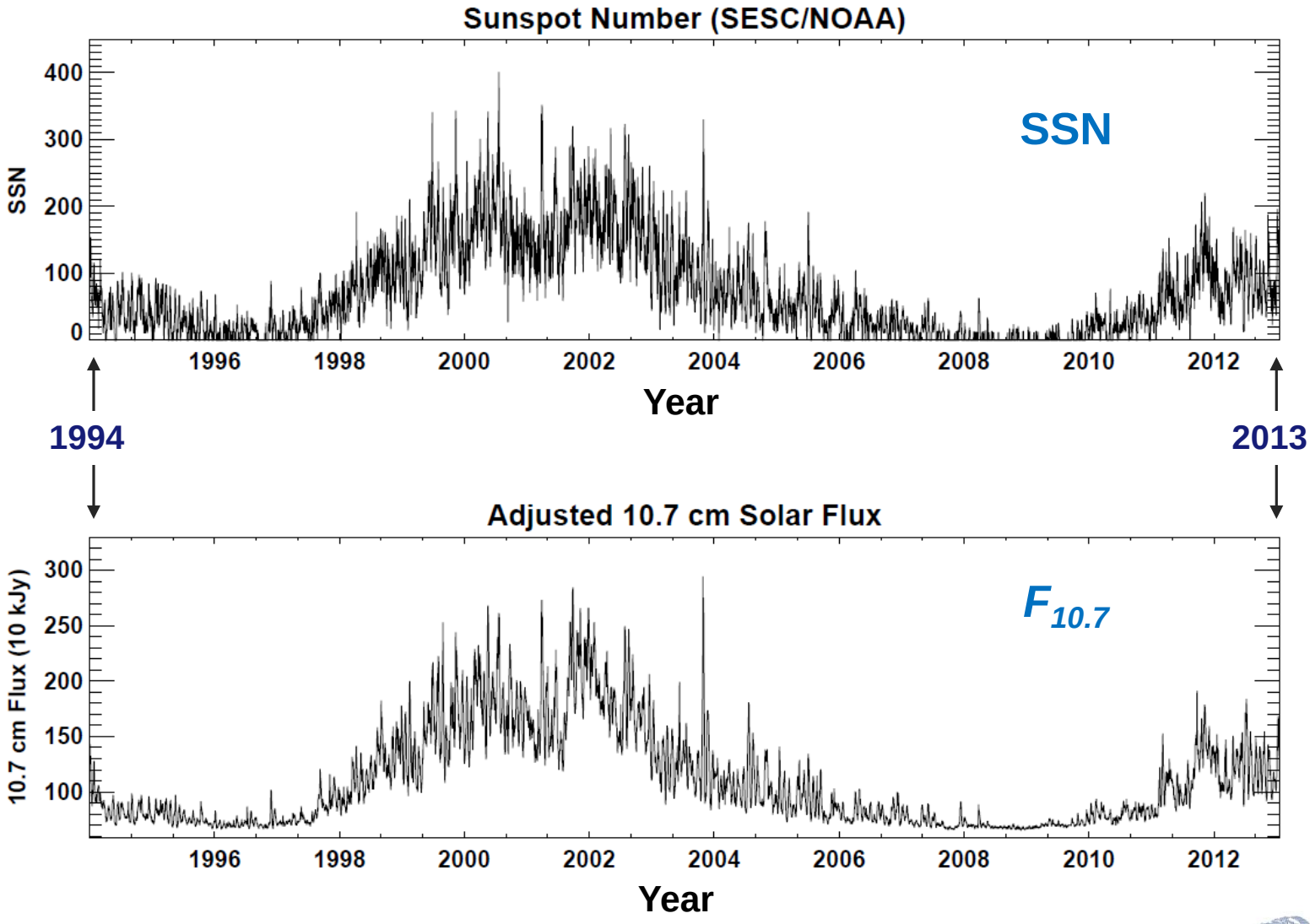
# Solar Indices

- Solar extreme ultraviolet (EUV) radiation is absorbed in the Earth's upper atmosphere (drives ionization & heating)

- Several solar indices have been used as proxies for EUV for periods without measurements at 10-120 nm, for example, the sunspot number (SSN), solar radio flux at 10.7 cm ($F_{10.7}$) and the Mg II core-to-wing ratio

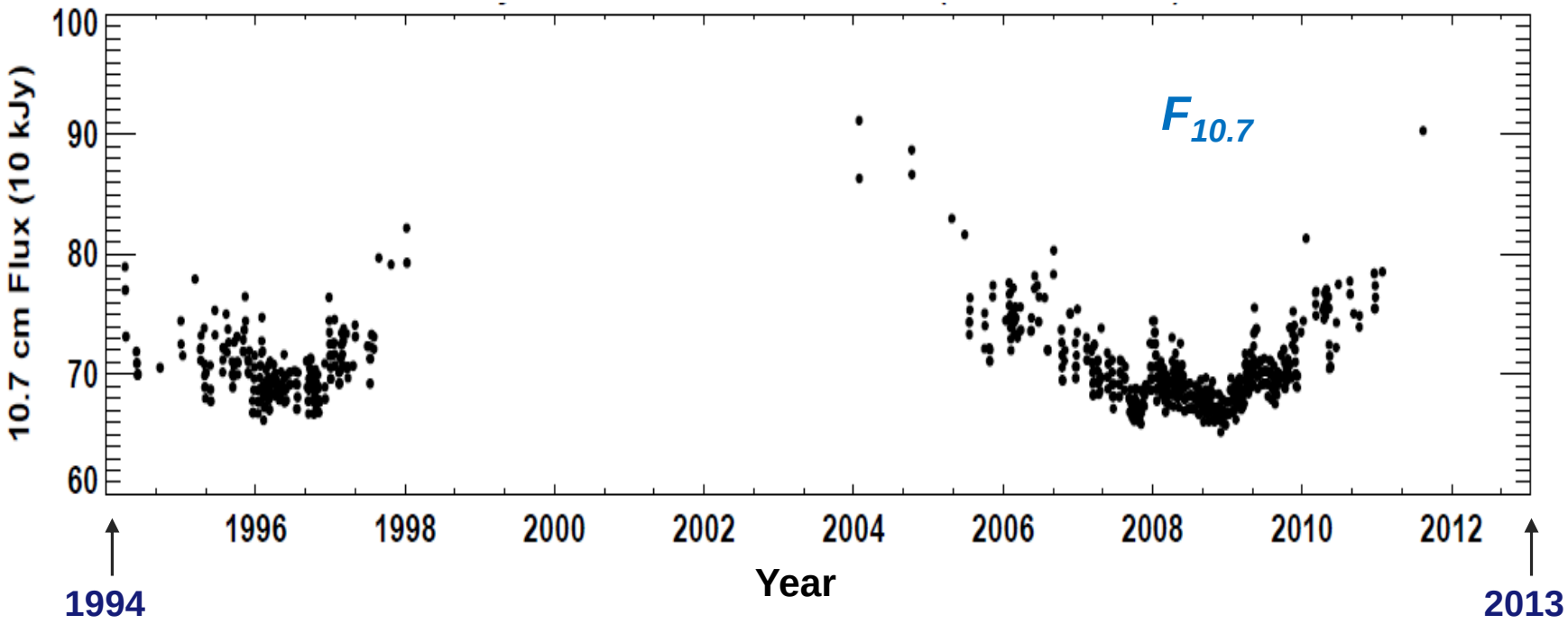
- Even with regular EUV irradiance observations (i.e., TIMED/SEE), solar $F_{10.7}$ and the Mg II Index are still used as the primary input to ionospheric, thermospheric, and orbital drag models

# Sunspot Number & $F_{10.7}$

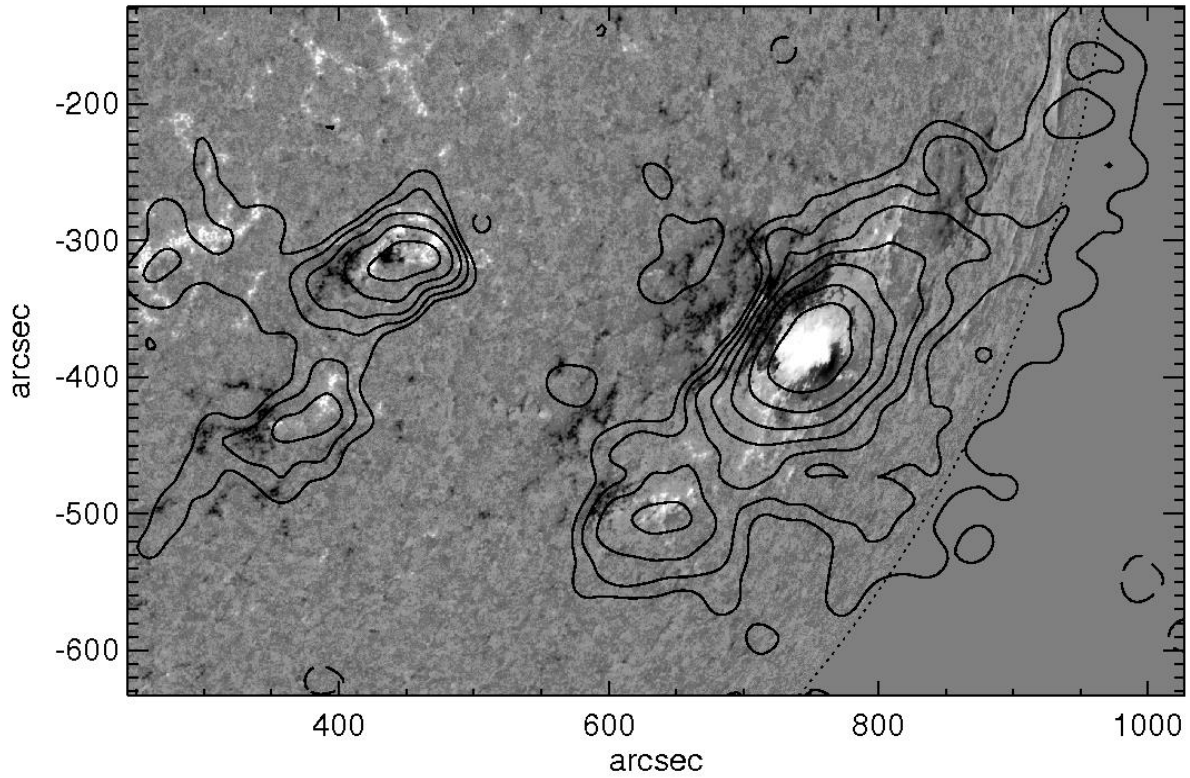


# Sunspot Number & $F_{10.7}$ (cont'd)

Observed $F_{10.7}$ values when SSN=0



# *Solar $F_{10.7}$* & Magnetic Field




VLA observation at 2.8 GHz (10.7 cm) from Dec 9, 2011; courtesy of Stephen White (AFRL). Contours are radio flux; background image SDO/HMI magnetogram.

**For more discussion on *$F_{10.7}$* sources, see:**
***Schonfeld et al. 2015, ApJ, 88, 29***

# $F_{10.7}$ & *VUV* Empirical Models

The F10.7 & VUV empirical models, based on Henney et al. 2012, use the near-side magnetic field estimates from the ADAPT maps:

$$F_{model} = m_0 + m_1 S_P + m_2 S_A$$

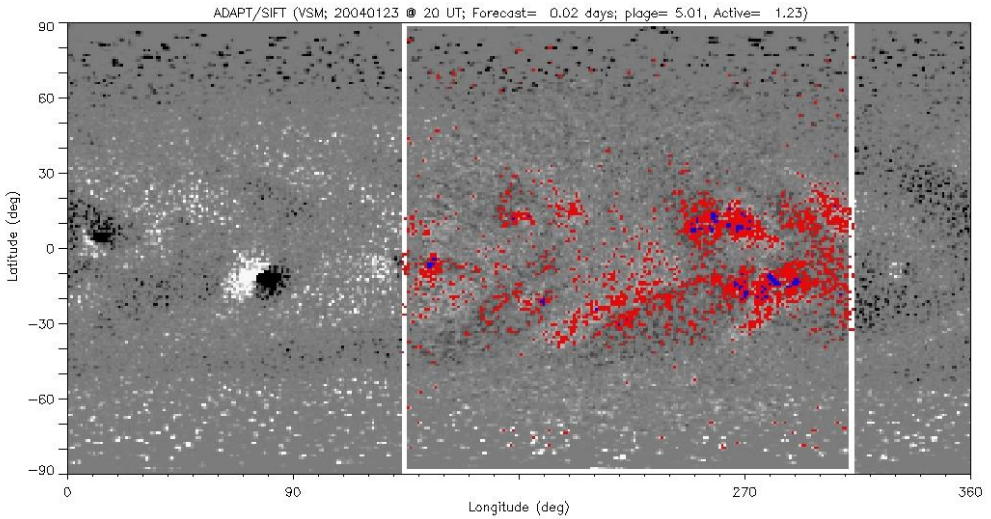
where

$$S_P = \frac{1}{\sum \omega_\theta} \sum_{25G<|B_r|}^{|B_r|<150G} |B_r| \omega_\theta$$

**Solar Weak Field**
["**Plage**"]

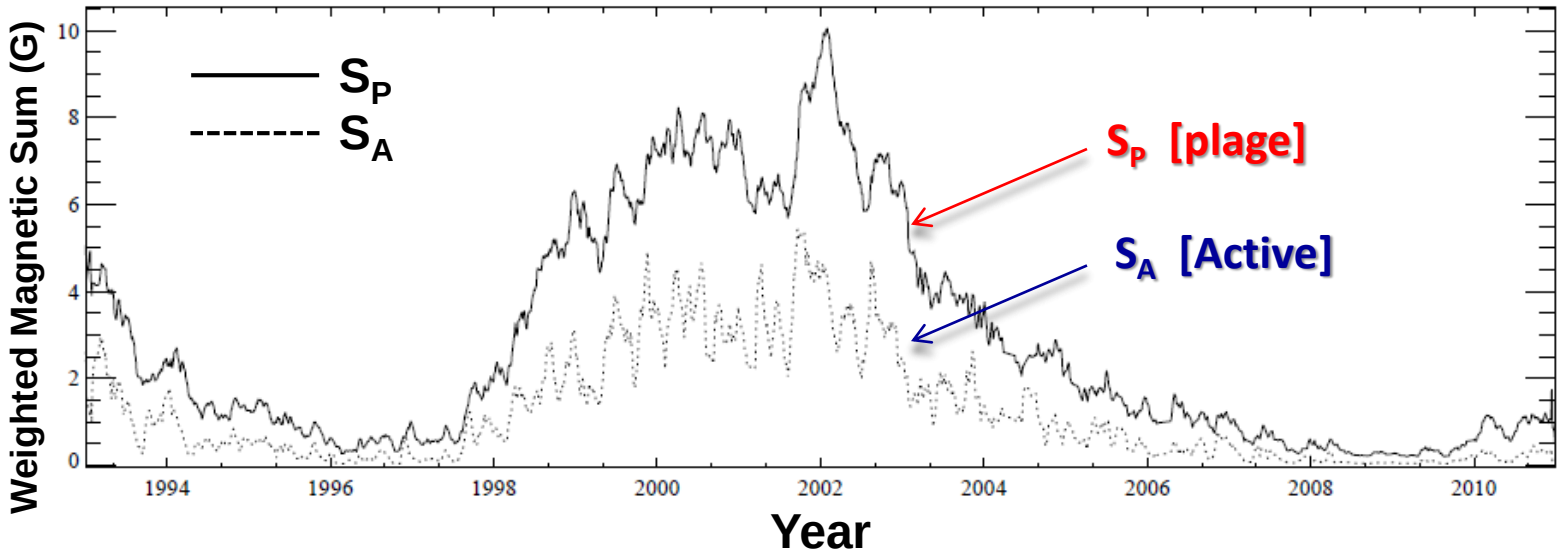
$$S_A = \frac{1}{\sum \omega_\theta} \sum_{150G \le |B_r|} |B_r| \omega_\theta .$$

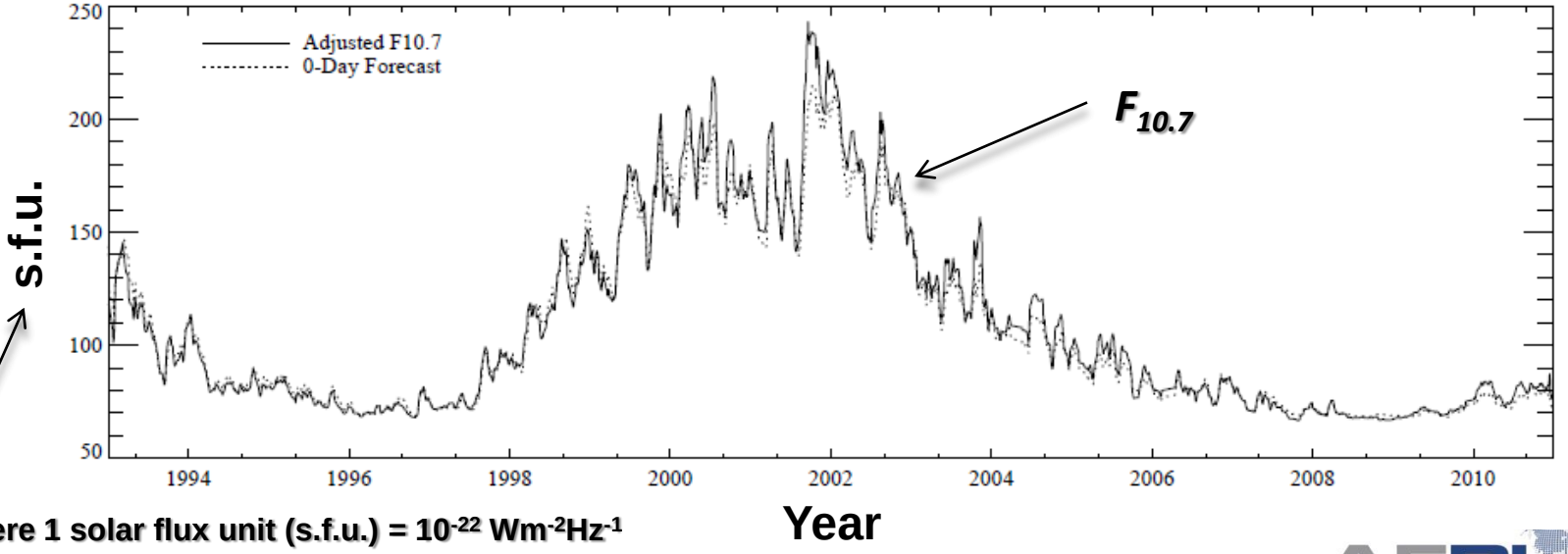
**Solar Strong Field**
["**Active**"]




**For more discussion on the $F_{10.7}$ & VUV modeling, see:**
***Henney et al. 2015, Space Weather, 13***

# ADAPT $F_{10.7}$ Model Nowcast



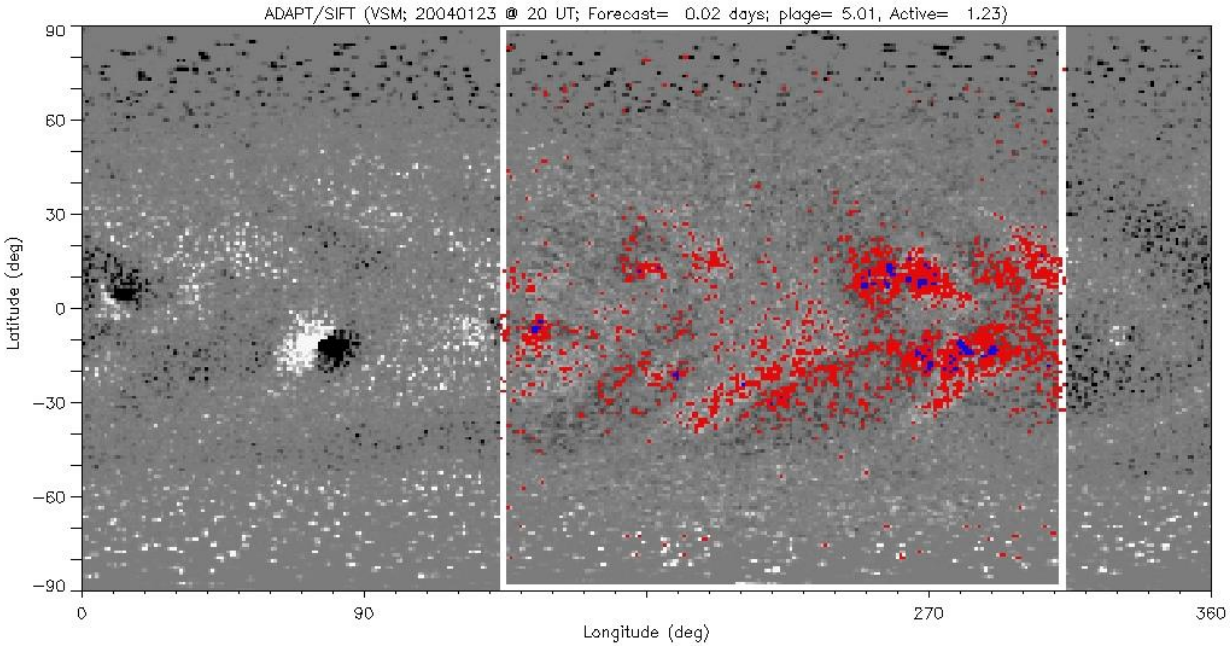

where 1 solar flux unit (s.f.u.) = $10^{-22}$ $Wm^{-2}Hz^{-1}$

*Henney et al., Space Weather, 10, S02011, 2012*

# Forecasting with ADAPT

ADAPT can generate global forecast maps, e.g., 1 to 7 days in the future, using magnetic flux transport modeling:

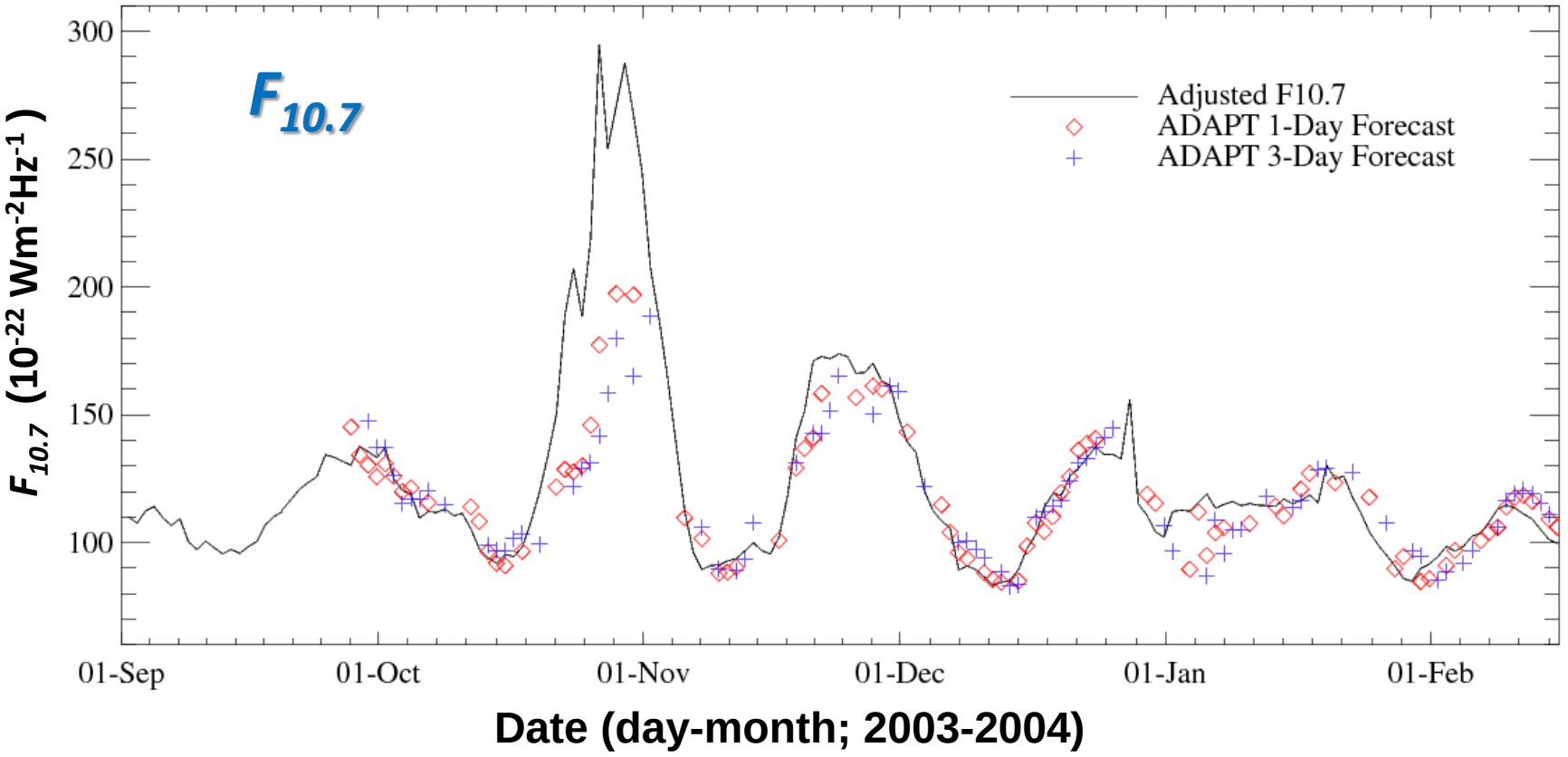
**7-day 3-day 0-day**



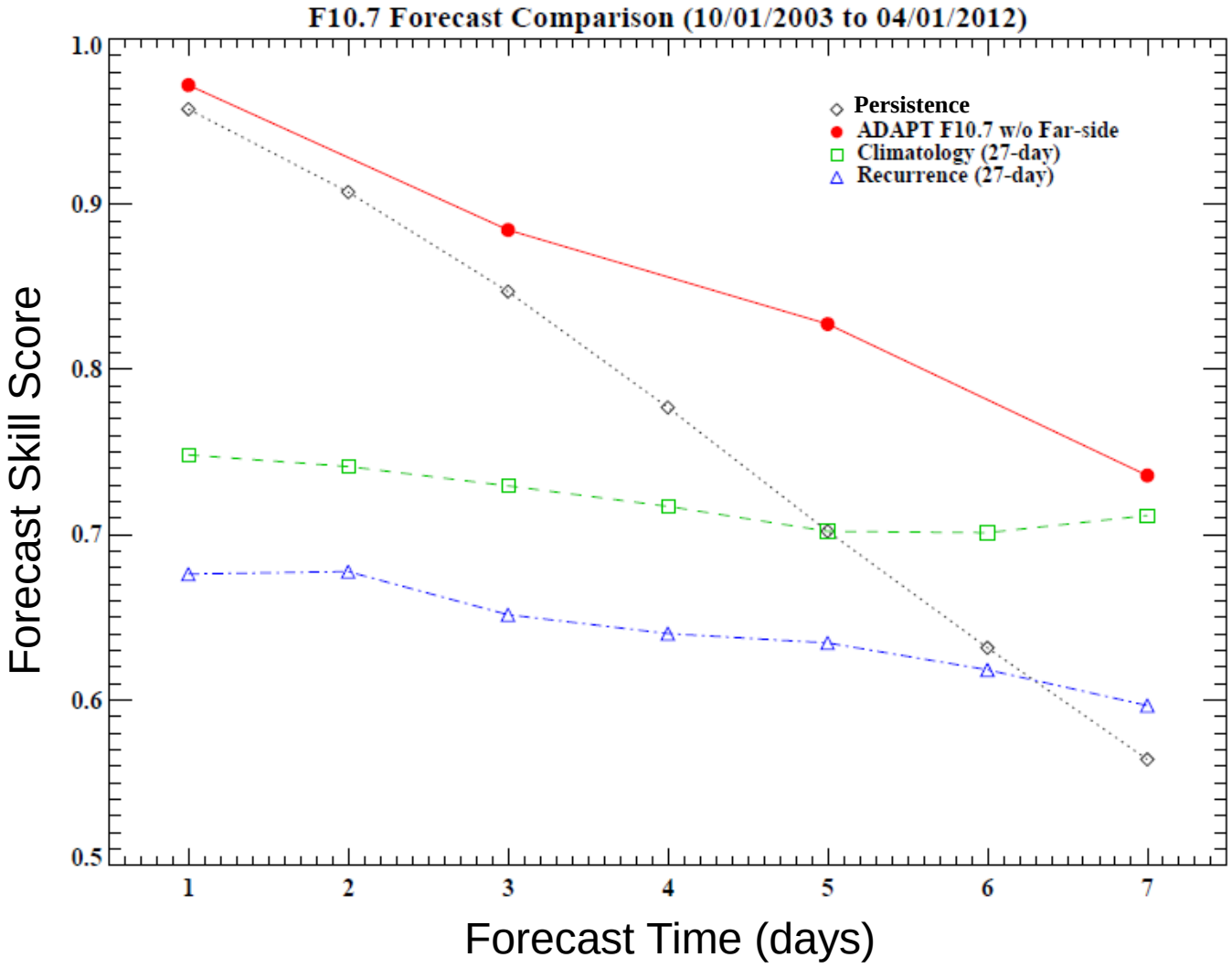

Global solar magnetic map (360 x 180 deg) created by ADAPT using NISP/SOLIS VSM data as input.

- ADAPT utilizes flux transport (*based on Worden & Harvey 2000*) to account for known surface flows in the solar photosphere:
  - **differential rotation, meridional circulation, supergranular diffusion**

# ADAPT Forecasting: $F_{10.7}$



# ADAPT* *F10.7 Skill Score*




**using ADAPT maps without far-side detection data*

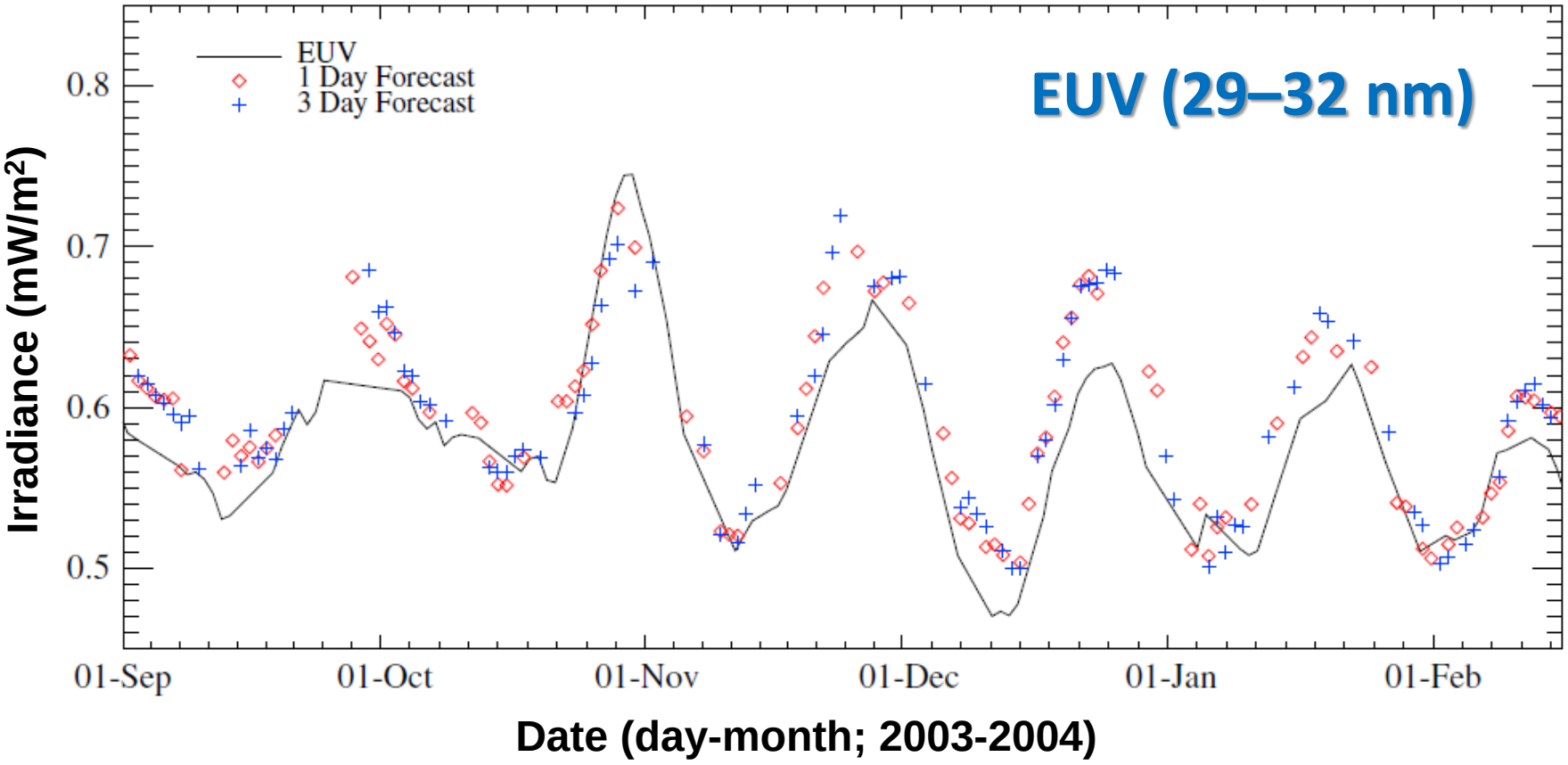
# Modeling XUV, EUV, & FUV

Thermospheric models typically divide the VUV spectral regions of interest into 37 bands within the **XUV/ EUV/FUV** intervals, where XUV is 0.1-10 nm, EUV is 10-121 nm, and FUV is 121-200 nm [Solomon and Qian, 2005]:

| # | Wavelength | # | Wavelength | # | Wavelength | # | Wavelength |
|---|---|---|---|---|---|---|---|
| 1 | 0.1-0.4nm | 11 | 54.0-65.0nm | 21 | 98.7-102.7nm | 31 | 140.0-145.0nm |
| 2 | 0.4-0.8nm | 12 | 65.0-79.8nm (low) | 22 | 102.7-105.0nm | 32 | 145.0-150.0nm |
| 3 | 0.8-1.8nm | 13 | 65.0-79.8nm (high) | 23 | 105.0-110.0nm | 33 | 150.0-155.0nm |
| 4 | 1.8-3.2nm | 14 | 79.8-91.3nm (low) | 24 | 110.0-115.0nm | 34 | 155.0-160.0nm |
| 5 | 3.2-7.0nm | 15 | 79.8-91.3nm (mid) | 25 | 115.0-120.0nm | 35 | 160.0-165.0nm |
| 6 | 7.0-15.5nm | 16 | 79.8-91.3nm (high) | 26 | 121.6nm Lyman-α | 36 | 165.0-170.0nm |
| 7 | 15.5-22.4nm | 17 | 91.3-97.5nm (low) | 27 | 120.0-125.0nm | 37 | 170.0-175.0nm |
| 8 | 22.4-29.0nm | 18 | 91.3-97.5nm (mid) | 28 | 125.0-130.0nm | | |
| 9 | 29.0-32.0nm | 19 | 91.3-97.5nm (high) | 29 | 130.0-135.0nm | | |
| 10 | 32.0-54.0nm | 20 | 97.5-98.7nm | 30 | 135.0-140.0nm | | |

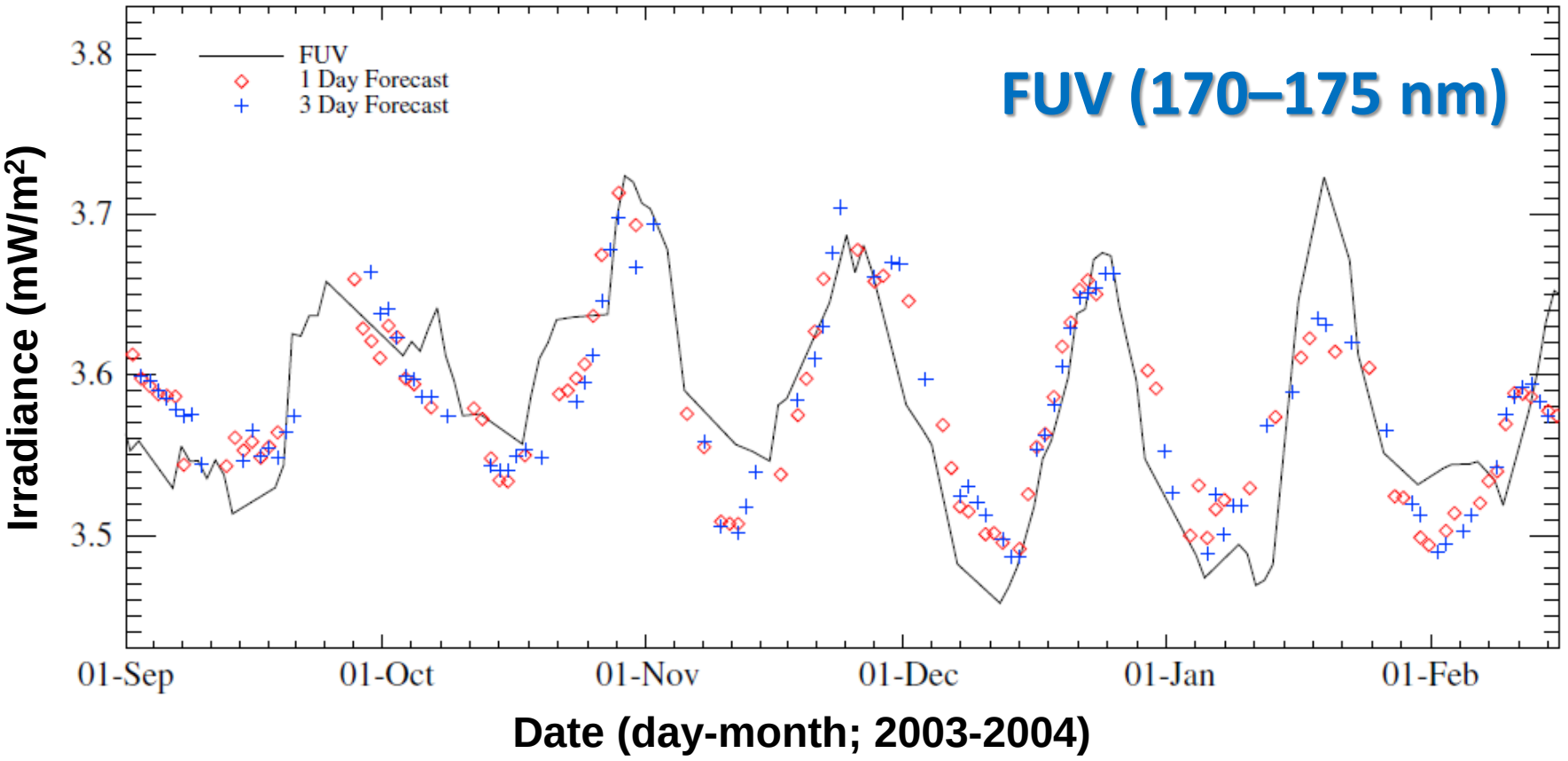
- For this study, we used solar irradiances measured by the Solar EUV Experiment (SEE) on NASA's TIMED mission [Woods et al. 2002], which has been operating since early 2002

# ADAPT Forecasting: EUV




*Henney et al. 2015, Space Weather, 13, 141-153*

# ADAPT Forecasting: FUV




*Henney et al. 2015, Space Weather, 13, 141-153*

# $F_{10.7}$ & *VUV* Model Comparison

The F10.7 & VUV empirical models are defined as:

$$F_{model} = m_0 + m_1 S_P + m_2 S_A$$

Weak Field Sum ["Plage"]

Strong Field Sum ["Active"]

Average linear correlation values, and ratio of model coefficients $m_1/m_2$, *for the period* ***2002 through 2010***:

| Band | 1-day | 3-day | 7-day | $m_1/m_2$ |
|---|---|---|---|---|
| **F10.7** | .99 | .97 | .95 | **.53** |
| **XUV** | .99 | .98 | .97 | **2.7** |
| **EUV** | .99 | .98 | .97 | **3.2** |
| **FUV** | .99 | .98 | .97 | **2.5** |

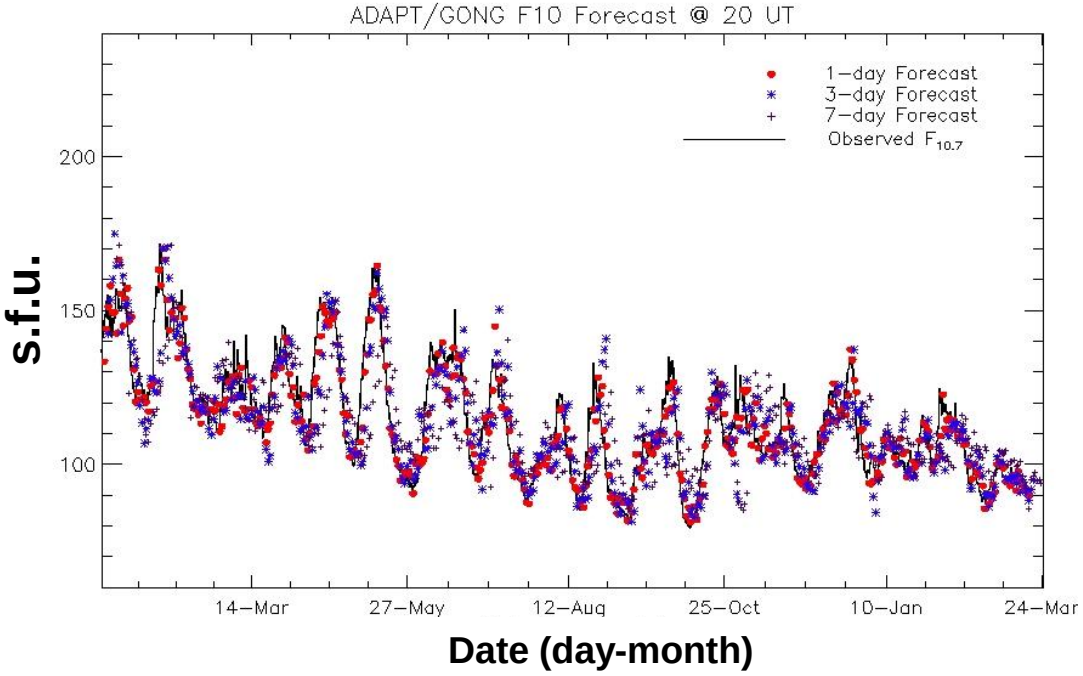
**F10.7 modeled well with strong solar magnetic fields, and XUV/EUV/FUV modeled well with weak fields.**

# ADAPT *F10.7 Model Online*

***$F_{10.7}$* model forecasts are now online:**

- **ADAPT runs 24/7 at the National Solar Observatory (NSO) generating global maps every 2 hours**

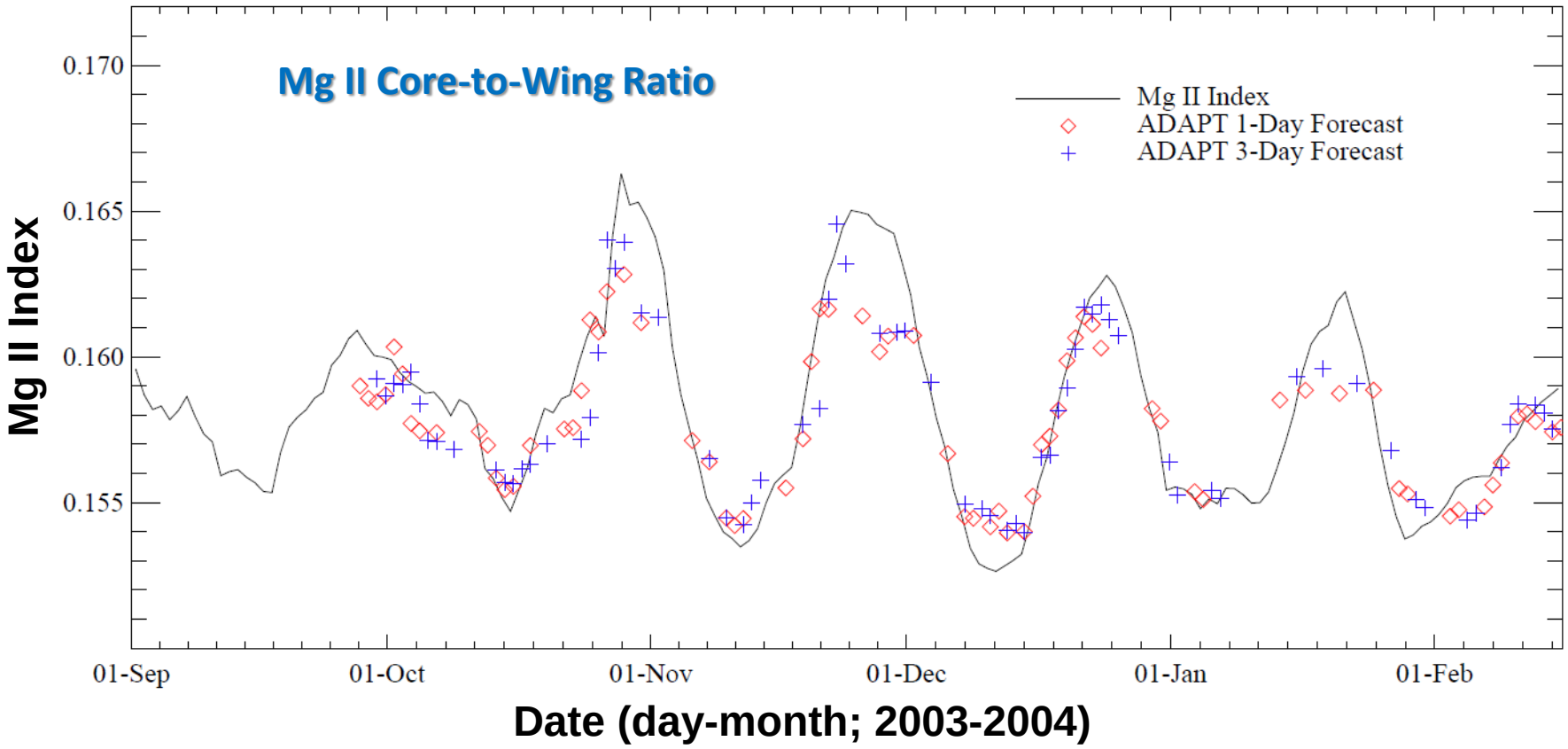
- **F10.7 model utilizes the ADAPT maps in near real-time, providing 1, 3, and 7 day advance forecast values of *F10.7***




```
: Product : adapt_f107_forecast.txt
: Created : 2014 10 24 2147 UT
: Date : 2014 10 24
: DOY : 297
: Model: ADAPT-F10.7
: Version :  5.0212
: POC : CJ Henney (USAF/AFRL)
: POC Email : adapt@noao.edu
: Data Input : GONG
: Resolution [deg / pixel] : 1.00
: Fit-function : m0 + m1*M_P + m2*M_A
: Forecast :  0,     1,     3,     7
: m0 :    66.08,  65.00,  64.00,  63.00
: m1 :     8.51,   8.00,   9.00,  10.00
: m2 :    16.56,  17.00,  18.00,  19.00
: M_P (plage mag-field) Lower Limit [G] :  25.0
: M_A (active region mag-field) Lower Limit [G] : 150.0
: Missing Value :  -1.0
: Record Count : 12
#
#| Table Notes
#
#   JD - Julian Date
#    M - Missing = 0 - forecast available
#              = 1 - forecast missing or pending
#    Q - Quality = 0 - input data nominal
#              = 1 - entry with >2 days w/o model input data
#    H - Helioseismic data within forecast window:
#              = 0-none, 1-farside, 2-nearside, 3-both farside & nearside
#   UT - forecast time, Coordinated Universal Time, HHMM format
#   LastMag - fractional days since last mag data assimilation
#   NearF10 - fractional days since last F10 obs differenced w/ 0d value
#   Diff - obs_model offset = (F10.7 obs value) - (0-day model prediction)
#   F10.7 Forecast - 0day, 1day, 3day, 7day model estimates plus diff offset
#
#| Observed F10 Data Source
#
#   http://www.swpc.noaa.gov/ftpdir/lists/radio/7day_rad.txt
#
#| ADAPT - F10.7 Forecast [s.f.u. @ earth distance]
#
#      JD        M  Q  H   UT    LastMag  NearF10  Diff     0d      1d      3d      7d
#-------------------------------------------------------------------------------------
  2456954.5000  0  0  0  0000    0.087    0.042    33.0   202.0   207.2   212.4   144.0
  2456954.5833  0  0  0  0200    0.011    0.125    33.0   204.9   209.9   214.8   144.7
  2456954.6667  0  0  0  0400    0.004    0.208    33.0   204.2   209.1   213.9   143.9
  2456954.7500  0  0  0  0600    0.087    0.292    33.0   203.1   208.5   212.5   143.0
  2456954.8333  0  0  0  0800    0.171   -0.375    52.9   222.0   227.8   231.0   162.3
  2456954.9167  0  0  0  1000    0.254   -0.292    52.9   221.0   227.4   230.5   161.7
  2456955.0000  0  0  0  1200    0.338   -0.208    52.9   220.1   227.1   230.0   161.4
  2456955.0833  0  0  0  1400    0.421   -0.125    52.9   219.3   226.7   229.4   161.3
  2456955.1667  0  0  0  1600    0.504   -0.042    52.9   217.7   226.5   228.6   160.9
  2456955.2500  0  0  0  1800    0.587    0.042    52.9   215.7   226.3   228.0   160.8
  2456955.3333  1  1  0  2000   -1.000   -1.000    -1.0    -1.0    -1.0    -1.0    -1.0
  2456955.4167  1  1  0  2200   -1.000   -1.000    -1.0    -1.0    -1.0    -1.0    -1.0
```

*Example ADAPT $F_{10.7}$ Forecast File*

# *New* ADAPT Forecast: Mg II Index



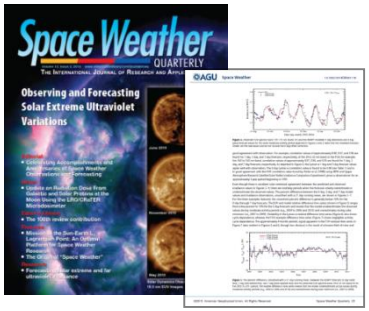

- Mg II Index from GOME/SCIAMACHY (via Mark Weber; Composite V5).

# Summary

- **Near real-time ADAPT maps & $F_{10.7}$ forecasts (1, 3, and 7 day) are public via the NSO at: ftp://gong2.nso.edu/adapt/f10/**

- **Near-future additions:**
  - **EUV power (0.8-105 nm) & Mg II Index forecasts**
  - **far-side detections within ADAPT maps**

- **For more details, see:**




***Forecasting Solar***
***Extreme and Far Ultraviolet Irradiance***
*Henney, Hock, Schooley, Toussaint, White, Arge 2015,*
***Space Weather, 13, 141-153***
***& Space Weather Quarterly, 12, 19-31***

**Acknowledgements**
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